MOBILE DATA COLLECTION AND PROCESSING SYSTEM AND METHODS

Field of the Invention

[0001] The present invention relates to the field of data collection, and, more particularly, to mobile mapping systems and road database management and related methods.

Background of the Invention

[0002] Accurate position of roads is useful in many commercial and government applications ranging from real time vehicle navigation systems to the definition of boundaries (congressional, municipal, voting districts).

[0003] The MAF, or Master Address File, is designed to be a complete and current list of all addresses and locations where people live or work, covering an estimated 115 million residences, as well as 60 million businesses and other structures in the United States. TIGER®, or Topologically Integrated Geographic Encoding and Referencing data is a digital database that identifies the type, location and name of streets, rivers, railroads and other geographic features, and geospatially defines their relationships to each other, to the

MAF addresses, and to numerous other entities. The two databases are maintained by the U.S. Census Bureau's Geography Division.

[0004] The MAF/TIGER Accuracy Improvement Program (MTAIP) is a major improvement to the quality and accuracy of the Census Bureau's digital geographic data which will be used by U.S. census takers in 2010 and beyond. The program will enable census takers to more precisely conduct their research and tabulations, and will ultimately result in an advanced, easy to update digital database that accurately reflects all of the nation's geographic census data. The MTAIP has a requirement to collect road centerlines at sufficient horizontal accuracy to support a final deliverable product of 5 meters (CE95).

[0005] Roughly 1/3 of all counties in the contiguous United States will require centerline collection. With over 11.3M kilometers of roads, the MTAIP will be collecting about 3.7M kilometers of centerline information. Assuming an average collection speed of 15 mph, there will be over 155,000 hours of collection time. Currently it is estimated that for every hour of collection time, another hour of post processing will be spent refining the data to meet the 5m requirement. The labor costs could be approximately $18M over the lifetime of the program. Any automation that can be applied to reduce the touched labor costs will have a dramatic impact on the overall cost of the program. There are several commercial and government programs that are gathering centerline road data, but not to the scale or accuracy required by the Census Bureau.

[0006] The most common approach is to outfit a van with a Global Positioning System (GPS) receiver (combined with Inertial Navigation System (INS) for dead reckoning), drive the roads, and ignore the differences between the van location and the

centerline. This approach does not meet the 5m requirement for roads with more than 2 lanes. A second approach is to drive the roads twice (once in each direction), average the 2 collections, and ignore errors introduced by lane changes. This approach is cost prohibitive for the number of roads MTAIP is collecting. A third approach is to record lane changes during the collection, and apply an average lane width offset to the van location as a post-processing step. This approach requires a high level of attention on the part of the operator to reduce human-induced error (2% error means 46,500 miles potentially outside of the 5m specification).

[0007] An example of a mobile mapping and data collection system that can map rail, highway and the transportation infrastructure (e.g., roads, signs, and bridges) while traveling at normal traffic speed is the GPSVan™ developed by the Center for Mapping at the Ohio State University. A Mobile Mapping System (MMS) can be defined as a moving platform, upon which multiple sensor/measurement systems have been integrated, to provide three-dimensional, near-continuous positioning of both the platform and simultaneously collected geo-spatial data. The Center for Mapping developed this technology, realizing that Geographic Information Systems (GIS) require up-to-date and high-quality spatial data to enhance the decision making process in transportation and urban planning. The GPSVan™ positioning module integrates the Global Positioning System (GPS) in the differential mode, and an independent Dead-Reckoning System (DRS) that records the vehicle's position during temporary GPS data outages (satellite signal blockage by trees or other obstructions). The positioning of the vehicle is good to 10 cm when GPS data is available at three-second intervals. GPS data

outages of 30 s, 60 s and 120 s cause the positioning degradation to the level of 0.2 m, 0.4 m and 1.0 m, respectively. Additional attributes, i.e., road signs, bridges, etc., can be recorded by a system operator, using a PC keyboard, or the touch screen of the system's portable computer.

[0008] An imaging module of the GPSVan™ includes a stereo camera system that records stereo images of the roadway as the van moves down the highway. The stereo system is supplemented by an analog camera system that runs in continuous video mode, and captures a photographic log of the survey. Each video frame is time-tagged with the GPS signal, and geodetic coordinates (i.e., latitude, longitude and ellipsoidal height) are assigned to every image. Digital stereo pairs are processed in a post-mission mode to determine geodetic coordinates of objects such as road edges and centerlines, curbs, street signs, mile markers, etc., with a relative accuracy of 5-10 centimeters within 10-40 meters from the vehicle. The analog imagery provides information for urban planners and tax assessors, as well as the real estate and transportation industry. Data collected by the GPSVan™ can be converted into a format compatible with a GIS, and used by the rail and transportation authorities to establish management priorities, and control safety features, such as speed limits and location of the warning signs.

[0009] Similar to the Ohio State GPSVan™, LambdaTech and Transmap use forward and/or side looking stereo cameras coupled with GPS navigational equipment to map road features. Another company using similar features is Visat. One survey article is "Land Based Mobile Mapping Systems" by Cameron Ellum and Nase El-Sheimy published in Photogrammetric Engineering & Remote

Sensing for January 2002. Also, a Swedish system called the PhotoBus is documented by Gillieron et al. in the 3rd International Symposium on Mobile Mapping Technology. The Photobus system performs a survey of the painted road centerline using a GPS and a Charge-Coupled Device (CCD) camera mounted on a roof rack extending over the left side of the vehicle. The image footprint is about 2.8 meters long and 2 meters wide.

Summary of the Invention

[0010] In view of the foregoing background, it is therefore an object of the present invention to provide a more accurate mobile data collection system and method that can operate at higher speeds.

[0011] This and other objects, features, and advantages in accordance with the present invention are provided by a mobile data collection system including a positioning system to generate position and time data, and a down-looking line scan camera for mounting on a vehicle to obtain a series of line scan images of a path, such as a road. A data collection controller is connected to both the positioning system and the line scan camera to associate the line scan images with the corresponding position and time data.

[0012] The mobile data collection system may also include a database to store the line scan images and associated corresponding position and time data. Furthermore, the positioning system preferably includes a Global Positioning System (GPS) receiver and an Inertial Navigation System (INS). The system may use GPS in the differential mode for increased accuracy. The line scan camera may include a one-hundred-and-eighty degree fish-eye lens, and the data collection controller

may include a central processing unit and a frame grabber. A display device may be connected to the data collection controller to display the line scan images, and the data collection controller may include an image processor to identify and mark road features, such as road edges, lane markings and the centerline, in the line scan images.

[0013] Objects, features, and advantages in accordance with the present invention are also provided by a method for road-centerline data collection and processing including providing a positioning system in a vehicle to generate position and time data, mounting a down-looking line scan camera with a wide-angle lens on the vehicle, and moving the vehicle along a road and operating the line scan camera to obtain a series of line scan images of the road. Each line scan image is associated with corresponding position and time data from the positioning system, and the line scan images may be displayed and/or processed to identify and mark road features.

Brief Description of the Drawings

[0014] FIG. 1 is a schematic diagram of a mobile data collection system including a line scan camera in accordance with the present invention.

[0015] FIG. 2 is a more detailed schematic diagram of the mobile data collection system of the present invention.

Detailed Description of the Preferred Embodiments

[0016] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and

should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime notation is used to indicate similar elements in alternative embodiments.

[0017] With reference to Figs. 1 and 2, a mobile data collection system **10** in accordance with the present invention will be described. The system **10** includes a positioning/ navigational system **22** to generate position and time data, and a down-looking line scan camera **12**, for mounting on a vehicle **14** to obtain a series of line scan images of a path **16**, such as a road. The camera may be a Spark SP-14 black and white line scan camera, for example, available from Dalsa of Waterloo, Ontario, Canada.

[0018] The down-looking line scan (also known as a broom sweep because of the way it "sweeps" to form an image) camera **12** scans across the path **16** as the vehicle **14** travels. The line scan camera **12** can be fitted with various lenses. An example is a combination of the line scan camera **12** and a 180 degree fish-eye lens **36**, but other combinations are possible. Another possible design is to use two or more line scan cameras **12** angled so as to obtain higher resolution images of as wide a field as required. It would even be possible to scan upwards to capture details of overhead road structures. Advantages are that because the camera **12** takes images a single scan at a time the vehicle **14** can travel at higher speeds and collect a smaller volume of data than systems which use an area scan camera.

[0019] A line scan camera includes a CCD element, lens & driver control circuit. An image of an object, created on the

CCD element via the lens, and quantity of light is converted to a video pulse signal and then is output. The resolution of a line scan camera is approximately 10 times (10^2 times in two dimensions) higher than an area camera. A typical line scan camera can scan at 20 MHz (50 nsec/scan). Image capture speed by a line scan camera is considerably faster than the typical speed of an area camera. Also, in the inspection of a continuous object, e.g. the roadway, it's difficult to get synchronization with an area camera. However, continuous processing is more easily done with a line scan camera because of its video output of each scan.

[0020] The positioning system **22** preferably includes a Global Positioning System (GPS) receiver **24** and may also include an Inertial Navigation System (INS) **26** for obtaining positional data in areas where obstruction of GPS signals may occur. The system may use the GPS in the differential mode for increased accuracy, as would be appreciated by the skilled artisan. A data collection controller **20** is connected to the positioning system **22** and the line scan camera **12** to associate each line scan image with corresponding position and time data. In other words, each scan line is tagged with geospatial and time data. Imagery may be collected based on the vehicle **14** velocity. Scans may be collected at a lower linear resolution at higher speeds because the road position is unlikely to be changing rapidly.

[0021] The mobile data collection system **10** may also include a database **28** to store the line scan images and associated corresponding position and time data. Typically, the data collection controller **20** would include a central processing unit and a frame grabber **34**. A display device **30**, e.g. a touch screen monitor, may be connected to the data collection

controller **20** to display the line scan images. Also, an input device **38**, such as a keyboard, mouse, microphone etc., may be associated with the data collection controller **20** and the display device **30**. And, in connection therewith, the data collection controller **20** may include an image processor **32** to identify and mark road features, such as road edges, lane markings, road centerline, bridges, railroad crossings and overpasses, in the line scan images. For example, contrast filters/feature detection techniques may be used to track the centerline. An operator may seed a program by dropping points on the centerline. The operator may then re-seed the program when it loses confidence as would be appreciated by the skilled artisan. Imagery can be unrectified (image space), rectified in 1D (to remove lens curvature), rectified in 2D (ground space) or rectified in 3D (if multiple cameras are used, a three dimensional model of the drive path can be created).

[0022] A method aspect of the invention is directed to a method for road-centerline data collection and processing. The method includes providing the positioning system **22** in the vehicle **14** to generate position and time data, mounting the down-looking line scan camera **12** with a wide-angle lens on the vehicle, and moving the vehicle along a road **16** while operating the line scan camera to obtain a series of line scan images of the road. Each line scan image is associated with corresponding position and time data from the positioning system **22**, and the line scan images may be displayed and/or processed to identify and mark road features.

[0023] By using the down looking line scan camera **12** coupled with the Global Positioning System **24** and Inertial Navigation System **26**, one can determine the exact position of points along

either the centerline or edges of a roadway **16**. Done with sufficient resolution, a highly accurate map of a roadway system can be produced. The line scan camera **12** and navigational equipment **22** is supplemented with software which allows an operator to view the images and mark road features. An advantage of this invention is using image processing to automatically or semi-automatically (i.e. with operator assistance) identify road features such as (but not limited to) road edges and lane markings which can be used to determine the road centerline.

[0024] The approach is scalable for the number of roads the MTAIP is required to collect whereas the state of the art approaches are not. Other approaches may not provide a quality assurance check of the data collected whereas, in the present invention, the imagery shows the operator exactly what was collected. Some of the better prior art road centerline collections to date are at about 10 meters (CE95) accuracy, whereas the present invention is closer to about 1 meter (CE95) of accuracy. Thus, the present invention will produce more accurate centerline data with less labor.

[0025] The invention has the advantage of being able to use just one camera, whereas the state of the art approaches require a two camera stereo collection. Stereo cameras are required to determine the elevation difference between the location of the collection vehicle and the location of the portion of the road being captured due to the mounting of the cameras (forward looking at a shallow angle). The present invention uses a single line scan camera to capture the portion of the road just in front of or behind the collection vehicle. The elevation of the portion of the road being collected is nearly identical to the

elevation of the vehicle, and thus stereo imagery is not required. One drawback to using a single line scan camera is it is not possible to measure the crown or bank of the road directly from the collected data. The effect of road crown and bank has been analyzed and is considered to be acceptably low. However, a laser range finder may used to determine the crown and bank of the road.

[0026] The invention also has the ability of being able to view long stretches of road on a small computer screen without losing the ability to measure orthogonal to the road. After 1D rectification, the line scan image has a resolution that is nominally 2 inches in the direction of the road and 2 inches orthogonal to the road. For example, a 500x500 display window will show 1000 inches along the road and 1000 inches orthogonal to the road. The image viewer developed permits adjustment of the viewing resolution independently in each of the two image directions (along and orthogonal to the road). When the resolution is set to 20 inches along and 2 inches orthogonal to the road, the field of view in a 500x500 display window would be 10,000 inches along the road and 1000 inches orthogonal to the road. The ability to see and measure orthogonal to the road is affected very little. The lines on the road and the edges of the road are still quite visible. This is a distinct advantage in that it allows for a significant reduction in the time required to exploit the image and extract the true centerline of the road because it reduces the number of equivalent screens of data that need to be examined by an operator.

[0027] The invention could also be used in other mobile scanning systems, e.g. to scan for condition of roadways and railbeds. In addition to identifying road centerlines, it can be

used to accurately identify railroad intersection, start/stop of bridges/tunnels, and other significant road features. If multiple cameras are used, road signs, mile markers, telephone poles and other features located along roadways can also be identified. Products generated from this invention can be used for any system requiring highly accurate centerline data such as the automotive NeverLost systems.

[0028] Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.